Feasibility of sewage sludge-wheat straw co-composting amended with medical stone

Mukesh Kumar Awasthi[1,2], Quan Wang [1], Xiuna Ren [1], Junchao Zhao [1],Zengqiang Zhang[1*]

[1]College of Natural Resources and Environment, Northwest A&F University, Yangling, Shaanxi Province 712100, PR China

[2]Department of Biotechnology, Amicable Knowledge Solution University, Satna, India

* Presenting author email: zhangzq58@126.com

Abstract

In this study, the lab-scale co-composting of sewage sludge (SS) with wheat straw (WS) amended with medical stone (0%, 2%, 4%, 6% and 10%) was conducted for 42 days and evaluated gaseous emission and maturity parameters. The addition of medical stone evidently increased CO_2 production and reduced greenhouse gases (GHGs) emission. The combined addition of medical stonesignificantly improved the compost quality in terms of CH_4 and N_2O emission, nitrogen conservation and end product quality, especially, reduced 41.5% of NH_3 emission. That's because medical stonepossessed the complimentarily of free air space and contained plenty of degradable carbon source. The carbohydrates from combined addition of medical stonecould be utilized by thermophilic microorganisms, stimulate ammonia assimilation and reduce NH_3 emission. These results suggested that adding medical stonecould not only improve the degradation of organic matter and the quality of compost product, but also stimulate ammonia assimilation as well as reduced GHGs and ammonia emission.

Keywords: Sewage sludge; wheat straw; zeolite; composting; ammonia emission.

1. Introduction

In China, with the rapid urbanization and industrialization were gradually increasing capacity of municipal wastewater treatment, which produced huge amounts of sewage sludge (SS) are produced (Wang et al., 2011; Awasthi et al., 2016a). The annual production of SS are approximately 30 million tons in 2015, and its quantity grew by over 13% annually from 2007 to 2015 (Awasthi et al., 2016b). However, many methods for ecofriendly disposal of SS have been applied in last 10 years, such as incineration, landfilling, anaerobic digestion and composting (Chen et al., 2014). But in the above all methods, composting is one of the most widely-used ecofriendly and economical feasible techniques for the management of huge quantity produced SS (Bialobrzewski et al., 2015; Kulikowska, 2016). In this process, present organic matter is transformed into stable, pathogen-free end product like compost that is often used as a soil conditioner/organic fertilizer due to the high agronomic value of the end product. But SS cannot be composted alone due to the presence of high moisture and toxic compounds such as heavy metals (HMs), pathogenic microbes and poor gas permeability. Consequently, another disadvantage associated with SS composting is the release of greenhouse gas (GHGs) and ammonia due to the compaction of feedstock and rapid decomposition of nitrogenous material (proteins and amino acids).

However, the effects of different kinds of dry organic material as bulking agents have been widely studies in SS composting to reduce the GHGs, such as agricultural straw, biochar, pruning wastes and garden leaf (Nikaeen et al., 2015; Rashad et al., 2016; Sánchez-García et al., 2015). But ammonia emission obviously occurs during the thermophilic stage of composting, and normally at low initial C/N ratios, ammonia emissions from SS composting tend to be high (Liang et al.,2006). Thus, nitrogen loss and GHGs emission must be controlled during SS composting to enhance the agronomic value of the compost and reduce global warming impacts. In addition, another option is the required for SS co-composting, which combine different organic wastes to regulate the physicochemical parameters to the appropriate values before the start of composting (Zhang and He, 2006; Awasthi et al., 2016). Fernandez et al.(2010) reported that co-composting could provide optimum conditions for the rapid degradation of organic matter, such as suitable C/N ratio, high porosity and large active biomass, and what's more, meanwhile co-composting could dispose two or more kinds of organic solid waste.Therefore, the objective of present work was to study: (1) the influence of mixture of additives amendments on GHGs emissions;(2) the influence of mixture of maturity properties during DFSS composting.

2. Materials and methods

2.1. Raw materials collection and processing

The SS and wheat straw were used as raw materials in this investigation. SS was obtained from a local municipal wastewater treatment plant (Yangling, Shaanxi Province, China) and wheat straw (WS) was taken from the local agricultural farm research station of Yangling Northwest A&F University. Medical stone was purchased from Shijiazhuang Jiacheng Building Materials Co. Ltd., China. To achieve the appropriate moisture content (~55%) and C/N ratio~ 25, SS and WS were mixed at a ratio of 4:1 (dry weight basis).In addition, 1kg of plastic spheres was mixed with initial feed stock to adjust the initial bulk density to ~0.5 kg/L according to our previous work experience (Awasthi et al., 2016 a). The characteristics of raw materials are shown inour previous studies (Awasthi et al., 2017 and Wang et al., 2016).

2.2. Experiment design and compost sample collection

The composting process was performed in Polyvinyl chloride (PVC) reactors, each with a total working volume of 100-L under controlled ambient temperature; and systematic layout of the reactor and operational process is already described in our previous study. Seven treatments were conducted in triplicate to evaluate the effect of medical stone at 0%, 4%, 6%, and 10% (on SS dry weight basis) to determine the best optimum dosage of medical stone for GHGs emission reduction during SS composting. The SS+WS without any additives amendment was used as control for comparison purpose. About 100-L of each mixture was composted for 542 days in a reactor. Moisture content of the composting mixture was readjusted to 55% periodically on turning days 0, 3, 7, 10, 14, 21, 28, 35 and 42; meanwhile about 250g compost samples were collected from each treatment for further analysis. Fresh samples were separated into three parts; one part was air dried, properly ground, sieved through 0.1mm sieve and then used for total nutrients content analysis, while two other parts were stored as fresh sample on 4ºC and -20ºC for chemical and microbiological analysis. The composting biomass temperature was monitored every day four times (6h) by the using of thermocouple probe inserted into the center of the composting materials and averaged temperature was reported, respectively. Despite this the room temperature was also recorded. The thermocouple, air inlet and outlet pipes were disconnected from the reactor when the composting mass was turned and mixed.

2.3. Greenhouse gases and compost analysis

The GHGs and ammonia gas was collected, and analyzed according our previous study (Awasthi et al., 2016a). Moisture content was determined by oven drying at 105ºC till constant weight basis. Fresh compost samples 1:5 aqueous extract (dry weight basis) was used for the analysis of pH, electrical conductivity (EC), extractable ammonium (NH_4^+-N) and germination index (GI). The pH and EC were measured using pH meter with a glass electrode (INESA PHSJ-3F, China) and conductivity electrode (INESA DDS-307, China). Total organic matter (TOM), NH_4^+-N, total Kjeldahl nitrogen (TKN) and total organic carbon (TOC) were determined as per the standard Test Methods for the Examination of Composts and Composting(TMECC, 2002). All the physic-chemical and microbial analyses were performed in triplicate. Meanwhile data were subjected on the basis of two-way analysis of variance (ANOVA) and multiple comparison tests were also performed to compare the least significance difference (LSD) at p = 0.05 values using SPSS v.21 software package for windows.

3. Results and discussion

3.1. Effect of medical stone amendment on maturity index

The result indicated that temperature rapidly increase in 10% MS applied treatment during the first week of composting and achieved values more than 60ºC within two days (Fig.1a). Such rapid increase trend of temperature indicated fast degradation of feed stock due to the presence of readily-available organic matters (Manios et al., 2007; Li et al., 2012; Ermolaev et al., 2014). The temperature in the control and 4 %MSamendment treatments increased slowly and maximum temperature was observed during the first 7 days being 52ºC, while the maximum temperature of 10% MS amended treatment 66ºC on day 6 (Fig.1a). These high temperatures in 10% MS amended treatments were maintained during two weeks and then gradually decreased to 40-50 ºC after four weeks of composting, which is indicating the end of thermophilc phase. Beside this, control, and 4 %MS applied treatments showed lower temperature and short thermophilic phase and maximum temperature 57ºC were observed in control on day 15 and 58 in 4%MS amended treatment on day 9. The temperature of control and 4 %MS amended treatments decreased rapidly after a very short thermophilic phase due to the low pH that inhibited microbial growth.

The pH is one of the critical parameters influenced the microbial activities and GHGs emission during composting; and optimal pH 7.0-8.0 was suggested by earlier authors for efficient composting (Szanto et al., 2007; Wong et al., 2009; Ermolaev et al., 2014; Chan et al., 2016). The decreasing trend of pH was observed in all treatments at the early stage of composting as reported previously (Villaseñor et al., 2011; Yang et al., 2013). As shown in Fig. 1b, the pH of 10% MS mended treatments rapidly decreased from 7.75 to 6.73 and then gradually increase until the end of composting, which was likely due to the rapid degradation of organic matter and accumulation of organic acid. Consequently, the continuous organic carbon and nitrogen mineralization by microorganism, and the carbonate formation pH decreased, but as organic acids were decomposed and release of ammonium and volatile ammonia, which increases pH profile. The temperature and pH profiles were consistent with previous studies, and the underlying reason for the profile shape has been well explained (Beck-Friis et al., 2001; Sanchez-Monedero et al., 2010; Awasthi et al., 2016a,b).At the end of composting, the result indicated that10% MS amended treatments were in the range of satisfactory values of pH (7-8.5) and end product was well stabilized (TMECC, 2002), while control and 4% MS amended treatments was not well matured. The final compost statistical analysis results showed that there were considerable differences between 10% MS with 4 and 6 %MS amended treatments and control, respectively ($p < 0.05$).

Biological activities mainly responsible for the variations in the concentration of NH_4^+-Nbecause of the transformation of organic nitrogenous compounds into ammonium and ammonia gas, which are generated during the composting of initial feedstock (Szanto et al., 2007; Li et al., 2013; Chan et al., 2016). The results revealed that the concentrations of NH_4^+-N rapidly increased in all the MS amended treatments during early phases and then gradually stabilized at the end of the composting (Fig.3c), except control and 4% MS amended treatments. In control and 4%MSamended treatments, maximum concentrations of NH_4^+-N (4295.05±143.53mg/kg and 39274.12±138.06mg/kg) were observed on day 28 and then slightly decrease until the end of composting, which were comparatively higher than the NH_4^+-N contents in 10% MS amended treatments, respectively. This higher NH_4^+-N concentrations in control and 4%MS treatments were mainly due to low pH did not proliferate the microbial activity and then slowed down mineralization of organic nitrogenous compounds. Our result of NH_4^+-N is in line with the previous findings (Yang et al., 2013; Awasthi et al., 2017) for food and kitchen waste, (Villaseñor et al., 2011; Li et al., 2013) SS and GIScomposting (Awasthi et al., 2016a). Therefore, the additions 10% MS are crucial for exploiting the extra-benefits of additives such as alleviate the initial low pH, reduce the nitrogen loss and GHGs emission from the composting reactor. Hence, when the pH is neutral the ammonium adsorption onto MS will be higher with the rate of organic waste degradation increase under optimum pH (6.5-7.5) (Villaseñor et al., 2011; Maulini-Duran et al., 2013; Awasthi et al., 2016b). After the second week, the NH_4^+-N concentration significantly decreased, might be due volatilization of ammonia ion and nitrification, while in control and 4% MS amended treatment did not significantly buffer the pH and hence above the permissible limit of NH_4^+-N concentrations were observed at the end of composting, which indicate the immaturity of the compost (TMECC, 2002).

As shown Fig.1d, the solid C/N ratio in all treatments gradually decreased from the beginning composting process, due to the loss of TOC and nitrogen in the form of CO_2 and ammonia (Fig. 1d). Among the all treatmentsMS amended treatments the trend of C/N ratio profile similar, while in the control amended treatments behaved totally different, and the increasing trend of C/N ratio were observed that could directly correlate with the rapid loss of ammonia and slow mineralization of organic matter during the composting. In addition, several earlier scientists also reported that carbon dioxide and ammonia emission directly interlinked with mineralization of organic matter coupled with the increasing TKN and decreased TOC content of the compost (Wong et al., 2009; Wang et al., 2016). Thus, in 10% MS amended treatments, C/N ratio values reached maturation within 28 days of composting, which indicated that addition of higher dosage of MS applied treatment wasconsiderably reduced the duration of maturation for SS compost. Despite control and 4 % MS amended treatments; compost was not mature after 42 days indicating longer time need for maturation (Fig. 1d).

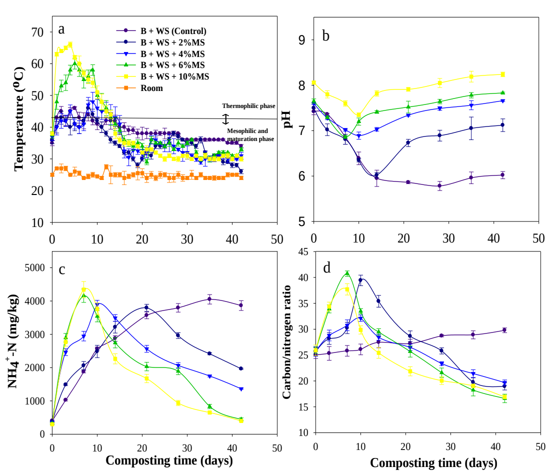

Fig.1. Changes in maturity index; temperature (a), pH (b), extractable ammonia (c), carbon/nitrogen ratio (d) in different treatments during composting of sewage sludge.

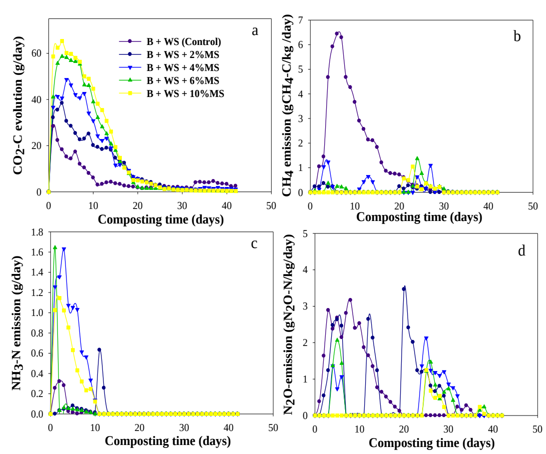

Fig.2. Changes in gaseous emission; CO_2 (a), CH_4 (b), NH_3 (c), N_2O (d) in different treatments during composting of sewage sludge.

3.2. Effect of biochar amendment on gaseous emission

The CO_2 emission was higher in all MS amended treatment, while maximum CO_2 emission was observed on day 2, and the emissions gradually decreased thereafter until the end of the thermophilic phase. The lowest CO_2 emission was observed, which reflects the maturation phase. In addition, low CO_2 emissions and high CH_4 emissions were observed in the control and 4% MS amended treatments, which clearly indicates the development of anaerobic pockets in both of these composting treatments. This inhibitory effectwas also reflected in the temperature and pH profiles of both treatments. The 10%MSapplied treatmentshowed CH_4 emission and a high CO_2 emission (Fig. 2a-b). The CH_4 and CO_2 emission profiles were consistent with previous studies, and the underlying reason for the profile shape has been well explained (Beck-Friis et al., 2001; Sanchez-Monedero et al., 2010; Santos et al., 2016). The NH_3 emission sharply increased from day 3-6 in the 2 and 4%MS amended treatment, and maximum ammonia loss was observed on day 7 (1.56 g/day) in the 6%MS amended treatment (Fig. 2c). In contrast, ammonia emission in the control treatment comparatively low throughout the composting process due to slow degradation of organic matter, and it could not be considered as an ammonia loss. A maximum of 22%-25% of the initial TKN was lost in the form of ammonia in the 2 to 4% MS amended treatment, while less than 8%-10% of TKN was lost from the 10%MS amended treatment (data not showen) at the end of composting. The NH_3 emission profiles from our study were generally consistent with several previous studies (Luo et al., 2013; Malinska et al., 2014; Sanchez-Garcia et al., 2015) but were higher than the result reported in Szanto et al. (2007), in which 2.5-3.9% of TKN was lost in the form of ammonia with a 4% biochar amendment. The maximum N_2O emission was observed in the control and 2 to 4% amended treatments from day 3-10 (Fig. 2d) and gradually decreased thereafter; this finding clearly indicates the presence of anaerobic pockets during the beginning of composting and may be the result of composting feed stock settlement reducing the O_2 availability. These anaerobic pockets formed despite the forced air ventilation and turning events supplied to all treatments to eliminate the anaerobic pockets in the composting matrix. Very low N_2O emissions were observed in the 10%MS amended treatment, which might be due to the rapid mineralization of organic matter, low nitrate concentration during the bioactive phase (data not shown) or dominant NH_4^+-N concentration (Fig. 1c). During the thermophilic phase of composting, N_2O emissions seemed to be responsible for a relevant fraction of TKN losses in the control and 4%MS amended treatments(data not shown). Similar findings were also obtained many researchers in previous studies (Szanto et al., 2007; Maulini-Duran et al., 2014; Morales et al., 2016), where the proportion of bulking agent, mixing of additives and turning frequency of the compostingmass were key factors in regulating the GHGs emissions and nitrogen losses.

4. Conclusions

Results indicated that composting of SS supplemented with 10%MS drastically reduced the CH_4, N_2O and NH_3 emissions and reached the compost maturity within 35 days. Taking into account compost quality, adding 10%MS was superior compare to the other two treatments for reached the thermophilic phase, reduced GHGs emission as well as alleviated low pH and achieved compost maturity. While control and 4% MS applied treatments was not matured on 42 days. Therefore, the best strategy by addition of 10%MScan reduce the GHGs emissions and facilitate nitrogen conservationduring SS composting and improve the compost quality.

5. Acknowledgment

The authors are grateful for the financial support from theChina Postdoctoral Science Foundation (No. 2016M602865)and post-doctoral scholarship from Northwest A&F University (No.154433). We are also thanks to our all laboratory colleagues and research staff members for their constructive advice and help.

6. References

Awasthi, M.K., Wang, M., Chen, H., Wang, Q., Zhao, J., Rena, X., Li, D.S., Awasthi, S.K., Shen, F., Li, R., Zhang, Z., 2017. Heterogeneity of biochar amendment to improve the carbon and nitrogen sequestration through reduce the greenhouse gases emissions during sewage sludge composting. Bioresour. Technol. 224,428–438.

Awasthi, M.K., Wang, Q., Huang, H., Li, R., Shen, F., Lahori, A. H., Wang, P., Guo, D., Guo, Z., Jiang, S., Zhang, Z., 2016a. Effect of biochar amendment on greenhouse gas emission and bio-availability of heavy metals during sewage sludge co-composting. J. Clean. Prod. 135, 829-835.

Awasthi, M.K., Wang, Q., Rena, X., Zhao, J., Huang, H., Awasthi, S.K., Lahori, A.H., Li, R., Zhang, Z., 2016b. Role of biochar amendment in mitigation of nitrogen loss and greenhouse gas emission during sewage sludge composting. Bioresour. Technol. 219, 270-280.

Beck-Friis, B., Pell, M., Sonesson, U., Jönsson, H., Kirchmann, H., 2000. Formation and emission of N_2O and CH_4 from compost heaps of organic household waste. Environ. Monit. Assess. 62, 317–331.

Fukumoto, Y., Osada, T., Hanajima, D., Haga, K., 2003. Patterns and quantities of NH3, N2O and CH4 emissions during swine manure composting without forced aeration-effect of compost pile scale. Bioresour. Technol. 89, 109–114.

Jiang, T., Ma, X., Tang, Q., Yang, J., Li, G., Schuchardt, F. 2016. Combined use of nitrification inhibitor and struvite crystallization to reduce the NH_3 and N_2O emissions during composting. Bioresour. Technol. 217, 210–218.

Li, R., Wang, J.J., Zhang, Z., Shen, F., Zhang, G., Qin, R., Li, X., Xiao, R., 2012. Nutrient transformations during composting of pig manure with bentonite. Bioresour. Technol. 121, 362–368.

Malinska, K., Zabochnicka-Swiatek, M., Dach, J., 2014. Effects of biochar amendment on ammonia emission during composting of sewage sludge. Ecol. Eng. 71, 474–478.

Sanchez-Monedero, M.A., Serramia, N., Civantos, C.G., Fernandez-Hernandez, A., Roig, A., 2010. Greenhouse gas emissions during composting of two-phase olive mill wastes with different agro-industrial by-products. Chemosphere 81, 18-25.

Steiner, C., Das, K.C., Melear, N., Lakly, D., 2010. Reducing nitrogen loss during poultry litter composting using biochar. J. Environ. Qual. 39 (4), 1236–1242.

Szanto, G.L., Hamelers, H.V.M., Rulkens, W.H., Veeken, A.H.M., 2007. NH_3, N_2O and CH_4 emissions during passively aerated composting of straw-rich pig manure. Bioresour. Technol. 98, 2659–2670.

TMECC (Test Methods for the Examination of Composts and Composting), 2002. In: Thompson, W., Leege, P., Millner, P., Watson, M.E. (Eds.), The US Composting Council, US Government Printing Office <http://tmecc.org/tmecc/index.html>.

Wang, C., Lu, H., Dong, D., Deng, H., Strong, P.J., Wang, H., Wu, W., 2013. Insight into the effects of biochar on manure composting: evidence supporting the relationship between N_2O emissions and denitrifying community. Environ. Sci. Technol. 47 (13), 7341–7349.

Wang, Q., Wang, Z., Awasthi, M. K., Jiang, Y., Li, R., Ren, X., Zhao, J., Shen, F., Wang, M., Zhang, Z. 2016. Evaluation of medical stone amendment for the reduction of nitrogen loss and bioavailability of heavy metals during pig manure composting. Bioresour. Technol. 220, 297-304.

Zhang, J., Lu, F., Shao, L., He, P., 2014. The use of biochar-amended composting to improve the humification and degradation of sewage sludge. Bioresour. Technol. 168, 252–258.